Top Quark Physics at DØ

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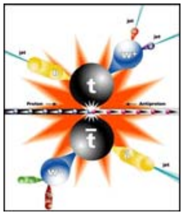
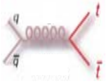
The Tevatron collider at Fermilab is currently the only accelerator able to produce top quarks.
The top quark is the heaviest known fermion, with the strongest coupling to the standard model Higgs boson.

Top quark physics allows to test the Standard Model and search for new physics
via precise measurements of the production rates, mass and decay properties.

Top Quark Pair Production and Decay



Within the Standard Model top quarks are predominantly **produced in pairs** at Tevatron energies via the strong interaction.



85% quark pair annihilation

15% gluon pair fusion

The expected **production rate** (cross-section) at $\sqrt{s} = 1.96$ TeV is 6.7 ± 0.7 picobarns [PRD 68, 114014 (2003)].

In the Standard Model both the top quark and the anti-top quark **decay** almost exclusively **into a b-quark and a W boson**. Thus, the final **signature of a top quark pair event** depends on the decay mode of the two W bosons produced. This leads to three possible configurations:

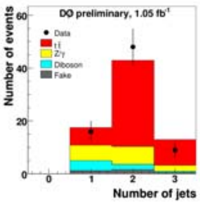
- both W bosons decay into leptons (~ 10%)
- one W boson decays leptonically while the other decays into a quark pair (44%)
- both W bosons decay into quarks (46%)

It is important to analyze these **different decay channels** as any significant difference observed among them would lead to physics beyond the Standard Model.

Top Quark Pair Production Cross Section Measurement

Dilepton Topological analysis

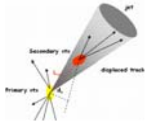
Events with 2 isolated leptons (e,μ), high missing transverse energy and at least two jets are selected. The dilepton events consistent with a Z boson decay are removed. The cross-section is measured from the excess of events with ≥ 2 jets over the background estimate.
Moreover, a similar analysis is carried out where only one lepton is identified while the second one is identified as an isolated track.



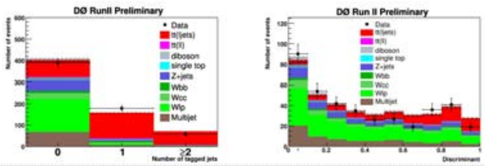
Comparison of the number of expected signal and background events with data after all selection cuts as a function of the number of jets.

Lepton+jets b-tagging analysis

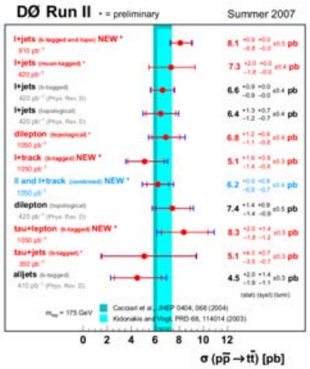
Events with one isolated lepton (e,μ), high missing transverse energy and ≥4 jets are selected in data. The signal content is enhanced by identifying heavy flavor jets originating from b-quarks making use of a **Neural Network tagger** algorithm.



The number of lepton + jets events with **0, 1 or 2 b-tagged jets** are counted and a **likelihood discriminant** based on kinematic properties of top pair events is used to further constrain the number of events without tagged jets. The result is the **best measurement to date** with uncertainties similar to the theoretical calculations.



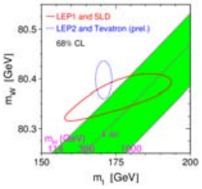
*Predicted and observed number of events as a function of the number of tagged jets (left).
Predicted and observed number of events with no tagged jets in bins of topological discriminant (right).*



Summary of the top quark pair production cross-section measurements performed in various channels in the DØ experiment.

Top Quark Mass

The **top quark mass** is a **fundamental free parameter** of the Standard Model. The mass of the top is the largest of any known fundamental particle. It **affects predictions of the Standard Model** via radiative corrections that relate the mass of the W boson and the top quark to that of the **Higgs boson**.



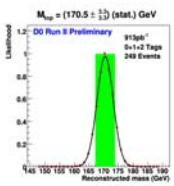
*Contour curves of 68% C.L. in the (m_t,m_W) plane for the indirect (LEP1 and SLD) and direct (LEP2 and Tevatron) determination in a global fit to electroweak precision data. Also shown is the correlation between m_t and m_W as expected in the SM for different Higgs boson masses (top right).
Virtual top and Higgs loops contributing to the W boson mass (top).*

Matrix Method with b-tagging

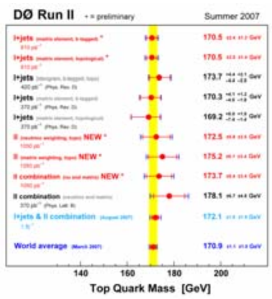
The top quark mass is measured with events with an isolated high p_T lepton, significant missing transverse energy and exactly four jets. The selected sample is split into three subsamples according to how many jets are b-tagged. A topological likelihood technique is used to estimate the signal and background fractions. For the given event kinematics the probability to be signal or background is calculated taking into account the differential cross-sections based on the **matrix elements**.

$$P_{t\bar{t}}(x; m_{top}, JES) = \frac{1}{\sigma(m_{top})} \int dq_1 dq_2 f(q) f(\bar{q}) d\sigma(y; m_{top}) W(x, y, JES)$$

b-tagging information is used to improve the selection of the correct jet-parton assignment. An **analytical likelihood method** is then used to extract the top mass.



Normalized likelihood as a function of the calibrated top mass.



Summary of top quark mass measurements in the lepton+jets and dilepton channels with DØ Run II data.

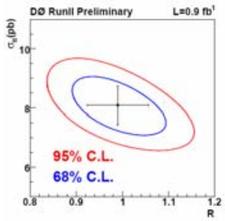
Top Quark Properties

Top Quark Branching Fraction Measurement

Assuming that the CKM matrix is unitary with exactly three quark generations, the standard model predicts :

$$R = \frac{B(t \to Wb)}{B(t \to Wq)} \approx 1$$

A measurement of *R* allows to test these assumptions. The measurement of *R* is performed via simultaneous fit with the production cross-section by comparing the number of events with one or two or more b-tagged jets.

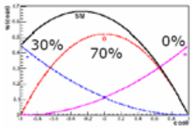


68% and 90 % confidence level contour regions in the (R, $\sigma_{t\bar{t}} \times B(t \to Wq)$) plane

The measured result of **R = 0.99±0.09(stat.+syst.)** and the limit **R > 0.81 at 95% C.L.** are the **most precise to date.**

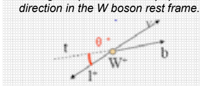
W-helicity Measurement

In the Standard Model, the W boson coming from a top quark decay is either **left-handed (f_- = 70%)** or **longitudinal (f_0 = 30%).** A measured fraction of **right-handed** W bosons **$f_+ \neq 0$** would be an unambiguous signature of new physics.

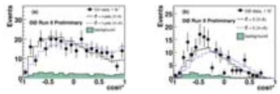


Standard Model predictions of the angular distribution for a charged lepton coming from W-boson decay.

The W boson helicity is measured through the angle θ between the charged lepton and the top quark direction in the W boson rest frame.



Top quark pairs with lepton+jets final states are selected and the four vectors of all final state particles are reconstructed. **f+** is extracted from a likelihood fit to the angular distribution of the charged lepton, **cos θ***.

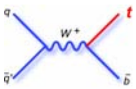


Lepton decay angle measured in data compared with the standard model prediction (solid line) and pure V+A model (dashed line).

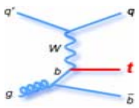
f_+=0.017±0.048(stat.) ± 0.047(syst.) and **f_+<0.14@ 95% C.L.** are currently the world's best measurements.

Single Top Production

Along with the observed strong pair production of top quarks the Standard Model predicts the single **production of top quarks via the electroweak force**. The dominant modes of single top production at the Tevatron are the **s-channel** and **t-channel** production.



30% s-channel at √s = 1.96 TeV



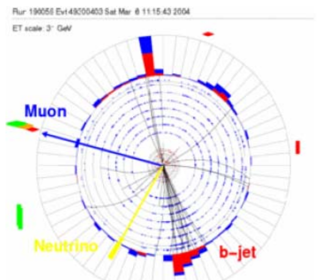
70% t-channel at √s = 1.96 TeV

The theoretical expected production rate (cross-section) at the Tevatron's center of mass energy of 1.96 TeV for this rare process is **2.9 picobarns** ($\sigma_{s\text{-channel}}$ = 0.88pb, $\sigma_{t\text{-channel}}$ = 1.98pb) [Z. Sullivan, PRD **70**, 114012 (2004)].

The study of the interaction vertex between a W-boson, a top quark and a bottom quark allows for a **direct measurement of the strength of the coupling** between these particles, the so-called **V_{tb}** element of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix. So far only indirect constraints exist on this fundamental free parameter of the Standard Model. Moreover, the interest of this process goes beyond the Standard Model:

- **New heavy particles** could enhance the production cross section in the s-channel
- **Anomalous couplings**, like those predicted from a 4th family of quarks or other exotic theories, would enhance the t-channel production.

The study of the single top production also allows for the measurement of the partial decay width Γ(t→Wb) and hence the top quark lifetime.

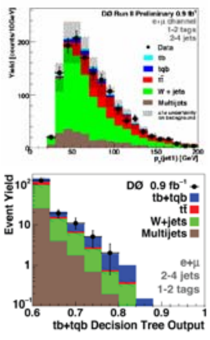


Candidate event

Evidence of Electroweak Top Production

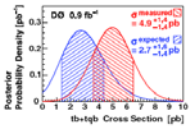
The analysis is performed on lepton + jets final states with a looser selection criteria than that of top quark pair analyses. The selection is loose intentionally so that **advanced multivariate techniques** can exploit the kinematic differences between the single top signal and backgrounds. A Neural Network tagging algorithm is used to identify jets originated from the hadronization of b-jets given that this jets are present in the signal events but not for most of the backgrounds.

Multivariate discriminants are build for each s- and t-channels and for the major backgrounds. These discriminants make use of the full kinematic information contained in the final states four-vectors (**Matrix Elements Analysis**) or by building machine-learning techniques like **Decision Trees** and **Bayesian Neural Networks** with variables that have discriminating power between signal and background.



Comparison of the observed and predicted distribution of one of the many input variables (top). Boosted Decision Tree output distribution for the high-discriminant region (bottom).

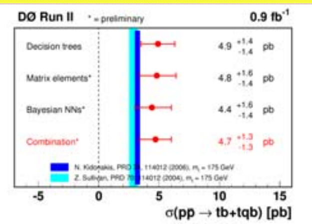
The single top **production cross section** is **measured** by means of a **Bayesian approach** in which a posterior probability density is computed as a function of the production cross-section.



The validity of the measurement is tested using ensembles of pseudo-datasets with different cross-sections. The expected and observed posterior probability densities are consistent with the Standard Model. We asses how strongly the analyses rule out a background-only hypothesis by measuring the probability for the background to fluctuate over the measured cross section; this probability is 0.035%. V_{tb} is also measured by computing a posterior probability density but now for $|V_{tb}|^2$.

σ_t= 4.7±1.3 pb (3.6σ significance)

$|V_{tb}f_1^L|$=1.3±0.2, assuming f_1^L=1**: 0.68<$|V_{tb}|$≤1 @ 95% C.L.**



Single top measurements for different analyses and the combination (top).

Projected sensitivity for single top quark observation (right).